SANDIA NATIONAL LABORATORIES
CIVILIAN RADIOACTIVE WASTE MANAGEMENT
TECHNICAL PROCEDURE (TP)

TP-094

LVDT CALIBRATION AT NEW ENGLAND RESEARCH, INC. (NER)

Revision 01

Effective Date: __10/09/03____

___Original Signed by Randolph J. Martin_______ ____10/03/03_____
Author: Randolph J. Martin III Date

____Original Signed by Ronald H. Price_________ _____10/03/03_____
Technical Reviewer: Ronald H. Price Date

_____Original Signed by James F. Graff_________ _____10/06/03______
Quality Assurance Reviewer: James F. Graff Date

(Reviewer signatures above document the review and resolution of comments.)

REVISION HISTORY

Revision	Description
0	Initial issue
1	TP-094 was deactivated during Audit BSC-ARC-01-010. It is now reactivated for additional work to be performed. No major technical revisions were required from the previous revision, only references to current procedures and other minor editorial revisions.

1.0 Scope and Objective

The objective of this Technical Procedure (TP) is to define the process for New England Research, Inc. (NER) to calibrate the Linear Variable Differential Transformers (LVDT) for use in mechanical properties experiments. This procedure is intended for implementation in a laboratory environment, in conjunction with work for the Yucca Mountain Project (YMP).

2.0 Prerequisites

Before performing work under this technical procedure, personnel must be trained by the author and/or the Principal Investigator (PI), and they must demonstrate their proficiency in performing the work in this procedure. The PI has the responsibility for generating a record of the personnel proficiency training, as well as the responsibility that work is performed and documented in accordance with this procedure.

The personnel using this procedure are responsible for ensuring that a controlled copy of this procedure is available and used for performing the work in this procedure.

3.0 Description of Activity

LVDTs are used to measure the displacements during compressional and constant stress tests. These tests are conducted under both room and high-temperature conditions. To accurately compute strains from displacement data, each LVDT must be capable of resolving displacements as low as 1×10^{-3} mm. Also, the output from each LVDT must be linear and accurate to $\pm$ 0.5% of its full-scale displacement. The output voltage of each LVDT (along with other data) is monitored and recorded by the data acquisition system (DAS) during experiments so that various mechanical properties may be calculated. It is critical to know the relationship between the output voltage of each LVDT and displacement. At least annual calibrations of the active LVDTs against a micrometer head with a certified calibration traceable to the National Institute of Standards and Technology (NIST) will ensure that correct values of displacement are being recorded during experiments. A Lancing Research Corporation linear translator (Serial No. NER-010-86) with a stroke of 0.254 mm is designated as the micrometer head used during these calibrations at the NER laboratory and will be calibrated on an annual basis by an independent calibration facility.

The LVDT calibrations are conducted upon individual LVDTs independent of the sample assembly set-up. The DAS is used in its experimental set-up configuration, and the LVDTs are configured as they are during experiments so that the calibrations are carried out in an "as used" condition. Each LVDT is calibrated under both ambient conditions and at high temperature, as they are subjected to these conditions during experiments. In this way, scaling factors can be determined for both conditions.

During this calibration, as during experiments, the LVDT output voltage is conditioned and amplified. The amplified output voltage is measured at the analog-to-digital converter of the DAS, and displayed on the video screen of the DAS. The values recorded on the LVDT Calibration Data Sheet (LCDS) (Appendix A) during the calibration will be read directly from the DAS screen. In this way, the response of the LVDT during calibrations, as measured by the DAS, will precisely reflect its response during experiments and systems calibrations.

The calibration is carried out in a calibration yoke consisting of a steel channel in which the Lancing micrometer is mounted into one side, and the LVDT barrel is mounted in the opposite side. A rod supporting the LVDT core is centered in the LVDT barrel. The micrometer is a rotating, screw type with a non-rotating stem. The nominal displacement of the head is 0.254mm. The total stroke is achieved in 40 revolutions or 6.35×10^{-3} mm per revolution of the micrometer drum. The accuracy of any displacement is $\pm$ 2.54×10^{-4}mm.

4.0 Activity Process

4.1 LVDT Calibration at Room Temperature

The LVDT is powered and conditioned with a signal conditioning system. The module excites the LVDT at a frequency of 5 kHz at 3.5 V RMS (Root-Mean-Square). The output of the secondary coils of the LVDT is demodulated and amplified by the signal conditioning system before being passed on to the DAS.

All calibration information will be recorded on the LCDS in accordance to the requirements specified in AP-12.1Q.

1. Document the unique identification of the subject LVDT on the LCDS.

2. Record the temperature under which the calibration is being made on the LCDS.

3. Make certain the LVDT is wired as it will be during experiments.

4. Place the LVDT core onto one end of the threaded, stainless steel extension rod. Screw the rod, with core, into the micrometer stem, making certain it is secure.

5. Adjust the micrometer to zero.

6. Position the fully instrumented LVDT barrel into the calibration yoke and over the core. Slide the barrel in until the core is nearly centered in the barrel. While observing the LVDT output voltage on the DAS screen, very carefully slide the barrel back and forth until the output is between 0.0 and 0.5 V. Lock the barrel in place with the set screw. This is the null position of the LVDT. Advancement of the micrometer stem, and hence the LVDT core from this position, results in increasingly positive output voltages.

7. Measure the input voltage (to within 10 mV) to the LVDT with a calibrated digital voltmeter. Record this value on the LCDS.

8. Record the output voltage (to within 10 mV) of the LVDT with the DAS while the micrometer is at zero. Record this value on the LCDS.

9. Advance the LVDT core a total of 0.254 mm in increments of 0.0254 mm. At each increment, record the output voltage of the LVDT on the LCDS versus the displacement position as indicated by the micrometer. The output voltage (to within 10 mV) is taken from the DAS screen.

10. Retract the LVDT core back to zero in increments of 0.0254 mm. Record the output voltage for each increment as in Step 9.

11. Readjust the micrometer to zero.

12. Repeat steps 9 and 10, then go on to Step 13.

13. Plot the calibration test results utilizing standard software. Plot the displacement measured with the standard micrometer as a function of the output voltage of the LVDT being calibrated. The mean slope of the least-squares fit lines to the advancing portion of these two sets of data is the scale factor (in mm/V) for the subject LVDT. Evaluate the results of the calibration in terms of accuracy, combined error (i.e., nonlinearity and hysteresis), and reproducibility.

    a. Accuracy: The mean deviation between the displacement values measured by the micrometer and those calculated for the subject LVDT using the new scale factor. This quantity is expressed as a percentage of the full-scale output of the subject LVDT.

    b. Combined Error: A combination of the following two errors. This quantity is expressed as a percentage of the full-scale output of the subject LVDT.

        i. Nonlinearity: The maximum difference in voltage between the calibration data and the linear fit to the data at a given displacement.

        ii. Hysteresis: The maximum difference between subject LVDT outputs for the same applied displacements; the two sets of data are obtained during the forward and reverse displacement cycles of the calibration.

    c) Reproducibility: The difference in the scaling factors determined during succeeding calibration runs. This quantity is expressed as a percentage of the previous scaling factor.

11. The calibrated LVDT must meet or exceed the tolerances given below:

    a. Accuracy: ±0.5%

    b. Combined Error: ±2%

    c. Reproducibility: ±2%

If the calibration results do not meet the specifications, the problem must be solved and an acceptable calibration performed prior to using the LVDT in further experiments.

4.2 LVDT Calibration at Elevated Temperature

The elevated temperature calibration is carried out in a similar manner to that of the room temperature calibration. Differences are in the design of the calibration yoke and the temperature at which the LVDT operates during the calibration. During the experiments at elevated temperature, the LVDTs monitoring sample displacement are subjected to temperatures well above ambient. Thermocouples are used to monitor the temperature of the LVDTs during the experiments. The calibration described in this section determines the effect of temperature on the LVDT scale factor; the results are used to correct the LVDT data collected during experiments at elevated temperatures.

The calibration yoke used in this calibration is a modification of that used during room temperature calibrations. The micrometer head is the same, however. The yoke is extended to twenty-four (24) inches and rather than being made of steel, it is made of fused quartz. Fused quartz has a very low coefficient of thermal expansion, and is therefore, less affected by the elevated temperatures it is subjected to during the calibration. The extension rod supporting the LVDT core is also made of fused quartz.

A thermostatically controlled laboratory oven is used to heat the LVDT during the calibration. A thermocouple/digital thermometer system is used to monitor the temperature in the oven, in proximity to the LDVT.

All other device configurations and recording mechanisms are the same as for the room temperature calibration.

1. Document the unique identification of the subject LVDT on the LCDS.

2. Record the temperature under which the calibration is being made on the LCDS.

3. Make certain the LVDT is wired as it will be during experiments.

4. Place the LVDT core onto one end of the fused quartz extension rod. Screw the rod, with core, into the micrometer stem, making certain it is secure.

5. Adjust the micrometer to zero.

6. Position the fully instrumented LVDT barrel into the calibration yoke and over the core. Slide the barrel in until the core is nearly centered in the barrel. While observing the LVDT output voltage on the DAS screen, very carefully slide the barrel back and forth until the output is between 0.0 and 0.5 V. Lock the barrel in place with the set screw. This is the null position of the LVDT. Advancement of the micrometer stem, and hence the LVDT core from this position, results in increasingly positive output voltages.

7. Insert the fully instrumented LVDT on the end of the calibration yoke into the oven so that the LVDT is approximately centered in the oven. Support the yoke to ensure it is secure.

8. Position the thermocouple tip near the LVDT barrel.

9. Place 4 in. of fiberglass insulation around the calibration yoke, and into the oven opening to seal the oven. Make certain there is no insulation interfering with the fused quartz extension rod.

10. Increase the temperature in the oven to the appropriate level (within $\pm$ 5^{o}C) at a rate not greater than 2^{o}C/min. Allow a minimum of fifteen (15) minutes for the equilibration of the system.

11. Check the LVDT output voltage on the DAS screen. If necessary, reposition the core by screwing the rod until the output voltage is between 0.0 and 0.5 V.

12. Measure the input voltage (to within 10 mV) to the LVDT with a calibrated digital voltmeter. Record this value on the LCDS.

13. Record the output voltage (to within 10 mV) of the LVDT with the DAS while the micrometer is at zero. Record this value on the LCDS.

14. Advance the LVDT core a total of 0.254 mm in increments of 0.0254 mm. At each increment, record the output voltage of the LVDT on the LCDS versus the displacement position as indicated by the micrometer. The output voltage (to within 10 mV) is taken from the DAS screen.

15. Retract the LVDT core back to zero in increments of 0.0254 mm. Record the output voltage for each increment as in Step 14.

16. Readjust the micrometer to zero.

17. Repeat steps 14 and 15, then go on to Step18.

18. Plot the calibration test results utilizing standard software. Plot the displacement measured with the standard micrometer as a function of the output voltage of the LVDT being calibrated. The mean slope of the least-squares fit lines to the advancing portion of these two sets of data is the scale factor (in mm/V) for the subject LVDT. Evaluate the results of the calibration in terms of accuracy, combined error (i.e., nonlinearity and hysteresis), and reproducibility.

    d. Accuracy: The mean deviation between the displacement values measured by the micrometer and those calculated for the subject LVDT using the new scale factor. This quantity is expressed as a percentage of the full-scale output of the subject LVDT.

    e. Combined Error: A combination of the following two errors. This quantity is expressed as a percentage of the full-scale output of the subject LVDT.

        i. Nonlinearity: The maximum difference in voltage between the calibration data and the linear fit to the data at a given displacement.

   ii. Hysteresis: The maximum difference between subject LVDT outputs for the same applied displacements; the two sets of data are obtained during the forward and reverse displacement cycles of the calibration.

c) Reproducibility: The difference in the scaling factors determined during succeeding calibration runs. This quantity is expressed as a percentage of the previous scaling factor.

12. The calibrated LVDT must meet or exceed the tolerances given below:

    a. Accuracy: ±0.5%
    b. Combined Error: ±2%
    c. Reproducibility: ±2%

    If the calibration results do not meet the specifications, the problem must be solved and an acceptable calibration performed prior to using the LVDT in further experiments.

5.0 Safety

There are no special safety hazards, only the normal hazards of the equipment. Operations will be in accordance with safety requirements of the facility where the work is being performed and that of the employer of person(s) performing the work.

6.0 Nonconformances, Deviations, and Corrective Actions

Any nonconformances or deviations must be reported to the PI as soon as possible. Deviations, deficiencies and corrective actions must be determined and documented in accordance with AP-16.1Q, *Condition Reporting and Resolution*.

7.0 QA Records

QA records, and any corrections or changes thereto, generated as a result of implementing this procedure will be prepared and submitted as inclusionary QA records (QA:QA) by the PI in accordance with AP-17.1Q, *Records Management*.

The QA records include:

- Proficiency training records (Section 2.0)
- Calibration records
- LVDT Calibration Data Sheets (LCDS) (Appendix A)

8.0 References

AP-12.1Q, *Control of Measuring and Test Equipment and Calibration Standards*

AP-16.1Q, *Condition Reporting and Resolution*

AP-17.1Q, *Records Management*

Appendix A

LVDT CALIBRATION DATA SHEET (LCDS)

Unique identifier of LVDT to be calibrated ____________________

Date of calibration ____________ Date of last calibration ____________

Calibration Procedure Number and Revision ____________________

Unique identifier of standard micrometer head ____________________

Date of last calibration of standard micrometer head ____________

Temperature condition: ____________ Input Voltage: ____________

First Cycle					Second Cycle			
Advancement		Retraction			Advancement		Retraction	
LVDT	Standard	LVDT	Standard		LVDT	Standard	LVDT	Standard

Calibration Results

Accuracy: ________% Combined Error: ________% Reproducibility ________%

Based on the evaluation of the accuracy, combined error and reproducibility of the data, the LVDT is (check one): In Specification ______ Out of Specification ______

Note: If "In Specification", the LVDT calibration is completed. If "Out of Specification", then note suspected problem(s) below, rerun the calibration and take appropriate steps to mark data collected with this LVDT since previous calibration.

Comments: ____________________

Work performed by: ____________________

Printed Signed Date

Company/Division: ____________________

Location of Work: ____________________